CONSEIL INTERNATIONAL DES UNIONS SCIENTIFIQUES
INTERNATIONAL COUNCIL OF SCIENTIFIC UNIONS

UNION GÉODÉSIQUE ET GÉOPHYSIQUE INTERNATIONALE
INTERNATIONAL UNION OF GEODESY AND GEOPHYSICS

Bulletin de l'Association Internationale d'Hydrologie Scientifique

N° 8

DECEMBRE 1957

Published on behalf of
THE INTERNATIONAL ASSOCIATION OF SCIENTIFIC HYDROLOGY
by
CEUTERICK
66, RUE VITAL DECOSTER
LOUVAIN (Belgium)

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I. LES PROPOS DU SECRÉTAIRE

1. Le présent numéro est le dernier de l'année 1957. Le secrétaire se permet de rappeler à chacun que le moment est venu de renouveler son abonnement et il vous invite à le faire sans trop tarder (3 $ par an).

2. Le Secrétaire attire d'autre part votre attention sur les communications importantes faites dans le présent bulletin et se rapportant à la distribution gratuite des publications, au Symposium sur la Physique du Mouvement de la Glace, au Symposium sur l'Eau et les Régions Boisées — les Lysimètres, à la présentation des rapports et communications aux Assemblées Générales, l'Organisation Météorologique Mondiale, etc.

3. Les communications présentées à Toronto sont à l'impression. Les auteurs recevront une épreuve et voudront bien indiquer le nombre de tirés à part qu'ils désirent en retournant l'épreuve corrigée. Le prix des tirés à part leur sera fourni avec l'épreuve. Il n'y a pas de tirés à part gratuits.

4. La bibliographie hydrologique commence à présenter un sérieux retard pour de nombreux pays. Nous invitons les membres responsables de cette activité de l'Association à combler ce retard en envoyant au Secrétaire de l'Association 450 exemplaires de leur nouvelle bibliographie. L'augmentation est due au nombre croissant des pays destinataires et à la remise faite à l'Organisation Météorologique Mondiale.

REMARKS AND NOTES BY THE SECRETARY

1. The present issue is the last one for the year 1957. The Secretary begs to remind everyone that the time has come for renewing subscriptions, and to invite them to do so without much delay ($ 3 yearly).

2. On the other hand he draws their attention to the important notices which appear in this bulletin and relate to the free distribution of publications, the Symposium on the Physics of Glacial Movement, the Symposium on Water and Woodlands, Lysimeters, the submission of reports and communications to General Assemblies, the World Meteorological Organization, etc.

3. The papers presented at Toronto are in the printer's hands. The authors will each receive a proof and should, when returning it corrected, kindly indicate the number of reprints required by them. The price of such reprints will be supplied with the proof. There is no free issue of reprints.

4. The hydrological bibliography is being seriously delayed by numerous countries. We invite the individuals concerned with this activity of the Association to make good the delay by sending to the Secretary of the Association 450 copies of their new bibliography. The increase in the number to be supplied is due to the growing list of the countries entitled to receive copies and to the World Meteorological Organization being given a quantity.

II. DISTRIBUTION DES PUBLICATIONS DE L'A. I. H. S.

1. *Comptes-Rendus et Rapports des Assemblées*

Il nous a parfois été reproché lors des réunions du Conseil et du Comité Exécutif de l'Union de distribuer gratuitement un nombre trop élevé d'exemplaires de nos publications.

D'autre part, il est un fait que les Finances de l'Association ne lui permettent plus semblable générosité.

Le Conseil de l'Association après avoir envisagé l'ensemble de la situation lors de ses réunions de Toronto a été d'avis qu'il convenait de réduire fortement ces distributions gratuites. La solution suivante a été défendue : chaque pays adhérent reçoit un nombre d'exemplaires des *Comptes-Rendus et Rapports des Assemblées égal à* $n + 1$, n étant le nombre de parts de 100 livres sterling chacune payées par ce pays comme cotisation à l'Union.

A partir des Comptes-Rendus et Rapports de Toronto, la distribution gratuite sera faite d'après cette règle.

2. *Bibliographie hydrologique*

La même règle sera adoptée à partir de 1958 pour la répartition de cette bibliographie, *cette distribution étant cependant limitée aux pays fournissant leur bibliographie à l'Association pour répartition entre les divers pays adhérents.*

3. *Bulletin de l'Association Intern. d'Hydrologie Scientifique*

Ce bulletin n'est envoyé gratuitement qu'à raison *d'un seul exemplaire* par pays et aux membres du bureau de l'Association.

4. *Informations hydrologiques*

Elles sont réparties gratuitement.

DISTRIBUTION OF PUBLICATIONS OF I. A. S. H.

1. *Proceedings and Papers of Assemblies*

Complaint is sometimes made at meetings of the Council and of the Executive Committee of the Union that we distribute too large a number of free copies of our publications.

On the other hand, it is the case that the finances of the Association no longer allow of such generosity.

The Council of the Association, after having surveyed the whole situation at its meetings in Toronto, has come to the opinion that it is proper to reduce markedly these free distributions. The following solution has been devised: each adherent country to receive a number, *equal to* $n + 1$, *of copies of the Proceedings and Papers of the Assemblies*, n being the number of amounts of £ 100 (sterling) each which is paid by the country as an annual subscription to the Union.

Beginning with the Proceedings and Papers of Toronto, the free distribution will be made according to this rule.

2. *Hydrological Bibliography*

The same rule as that above will be adopted from 1958 onwards for the apportionment of copies of this bibliography, this distribution being however confined to those countries which furnish their national bibliographies to the Association for apportionment between the several adherent countries concerned.

3. *Bulletin of the International Association of Scientific Hydrology*

A free copy of this bulletin is sent only at the rate of *a single copy* to each country and to each of the members of the bureau of the Association.

4. *Hydrological News-letters*

These are distributed free of charge.

III. PRÉSENTATION DES RAPPORTS ET DES COMMUNICATIONS POUR LES ASSEMBLÉES GÉNÉRALES ET NOTAMMENT POUR L'ASSEMBLÉE D'HELSINKI (1960)

Lors des dernières Assemblées, le nombre des Communications présentées s'est accru dans des proportions qui rendent difficiles l'organisation et notamment la discussion. De plus, l'impression de ces nombreuses études pose un problème financier que votre secrétaire risque de ne pouvoir résoudre.

L'essence même de l'U. G. G. I. et de ses Associations dont font en fait partie les organismes nationaux désignés par les gouvernements participants, nous conduit à rappeler que, logiquement, un seul rapport ou une seule communication peut être présenté par pays sur chaque question ou sujet mis à l'étude par l'A. I. H. S. Il appartient aux Comités Nationaux ou aux organismes qui les remplacent de limiter le nombre des communications comme il vient d'être dit. Pour plus de clarté, disons que pour chaque pays, il ne sera admis au grand maximum que :

1 rapport par sujet pour chacune des quatre commissions, soit tout au plus 3 rapports par commission;

1 rapport pour chacun des Comités des Précipitations et de l'Evaporation.

Il est cependant évident qu'un rapport national peut avoir été établi par divers auteurs, l'étendue de l'ensemble du rapport étant cependant soumise aux mêmes règles restrictives que la communication d'un seul auteur.

SUBMISSION OF REPORTS AND COMMUNICATIONS FOR GENERAL ASSEMBLIES AND PARTICULARLY FOR THE HELSINKI (FINLAND) ASSEMBLY OF 1960

At recent Assemblies the number of communications presented has increased to proportions which render difficult both organization and, especially, discussion. Beyond this, the printing of these numerous studies raises a financial problem that your Secretary may be unable to solve.

The very essence of the I. U. G. G. and its Associations, of which the national bodies designated by the participant Governments form in fact a part, causes us to recall that logically no more than a single report or a single communication may be submitted by a country on each question or subject set for study by the I. A. S. H. It is for the National Committees or the organizations which replace them to limit the number of communications in the way just said.

For greater clearness, let it be said that there will be accepted at the very most from each country no more than:

One report on each subject for each of the four commissions, with a maximum of three reports for any one commission.

One report for each of the Committees on Precipitation and Evaporation respectively.

It is obvious that a national report or communication can be provided by several authors, the extent of the document being however subject to the same restrictive regulations as the communication of a single author.

IV. ORGANISATION MÉTÉOROLOGIQUE MONDIALE (O. M. M.)

WORLD METEOROLOGICAL ORGANIZATION (W. M. O.)

Le Conseil Économique et Social des Nations Unies (ECOSOC) se préoccupe depuis longtemps de l'importance des problèmes posés par les Ressources en Eau. A la suite de ses multiples interventions, les Agences Spécialisées des Nations Unies (UNESCO, W. H. O., F. A. O. et W. M. O.) estimèrent qu'il importait que l'Organisation Météorologique Mondiale devienne l'organisme responsable des Nations Unies pour ces questions hydrologiques, comme cette organisation l'était pour le domaine météorologique.

On se souviendra sans doute que l'Organisation Météorologique Mondiale avait constitué un Groupe de Travail (Panel) chargé de l'éclairer sur l'activité possible de cette Organisation dans le Domaine du Développement des Ressources en Eau.

Ce Groupe est constitué de :

M. ARLÉRY (France)
M. GILEAD (Israel)
M. IVANOFF (U. R. S. S.)
M. KOHLER (U. S. A.)
M. TISON (A. I. H. S.)
M. WHITE (U. S. A.).

Ainsi qu'on le voit, M. L. J. TISON, Secrétaire de l'A. I. H. S. représentait cette Association au sein du groupe de Travail.

Les recommandations faites par le Groupe de Travail ont été reproduites dans notre bulletin n° 4.

Le Comité Exécutif de l'Organisation Météorologique Mondiale vient de prendre les décisions suivantes (Document EC-IX Doc. 128 Annex).

WMO PROGRAMME IN HYDROLOGY
(*Final number*: 6 (*EC-IX*))

THE EXECUTIVE COMMITTEE,

NOTING

Résolution 24 (Cg-II),
Recommendation 1 (WR-I);

DECIDES

1. That the WMO Programme shall include the following items in those aspects of Hydrology which fall within the common ground of Meteorology and Hydrology:

a) The preparation of Technical Regulations in Hydrology;

b) The preparation of a Guide or Guides on international practices in Hydrology;

c) The development of international standards for:

(i) Hydrologic observations and networks, including hours of observation and the units used;

(ii) The routine exchange of hydrologic data and forecasts;

(iii) Codes to be used for this exchange where the data are required urgently, for example between countries having a common river;

(iv) Forms of hydrologic yearbooks;

d) The incorporation of special maps for the use of hydrologists in the World Climatic Atlas and in Regional Climatic Atlases;

e) Collaboration with other organizations in the preparation and publication of a hydrologic terminology;

f) The preparation of Technical Notes on various aspects of Hydrology, for example, on methods used in hydrologic forecasting;

g) The organization of international symposia and training seminars;

2. That WMO shall continue to collaborate closely with the United Nations, the Specialized Agencies concerned and the International Association for Scientific Hydrology of the IUGG in all matters relating to Hydrology; and

REQUESTS the Panel on Water Resources Development to assist the Secretary-General in carrying out this programme; and

DIRECTS the Secretary-General

1. To communicate this Resolution to all concerned;

2. To implement the above programme insofar as available staff and resources permit.

Ce document ne mentionne pas la décision additionnelle finale au sujet de l'arrangement avec notre association, concernant la bibliographie hydrologique.

Le Secrétaire Général de l'O. M. M. me fait savoir que son Comité Exécutif a approuvé une subvention de 500 $ *en* 1958, *moyennant l'envoi de* 105 *exemplaires des bibliographies paraissant au cours de l'année.*

ORGANISATION MÉTÉOROLOGIQUE MONDIALE (O. M. M.)

WORLD METEOROLOGICAL ORGANIZATION (W. M. O.)

The Economic and Social Council of the United Nations Organization (ECOSOC) has concerned itself for a long while past with the importance of the problems arising from Water Resources. As a consequence of their several examinations of the matter, the Specialized Agencies of the United Nations Organization (UNESCO, the World Health Organization, the Food and Agriculture Organization and the World Meteorological Organization) judged it to be appropriate that W. M. O. should be the body responsible on behalf of the United Nations for hydrological questions, as it is for the meteorological domain.

One doubtless recollects that W. M. O. formed a panel (groupe de travail) which was required to inform the Organization on the possible extent to which it could act in the field of Water Resources Development.

The panel is composed of:

Mr. Arléry (France)
Mr. Gilead (Israel)
Mr. Ivanoff (U. S. S. R.)
Mr. Kohler (U. S. A.)
Mr. Tison (I. A. S. H.)
Mr. White (U. S. A.)

As will thus be seen, Mr. L. J. Tison, secretary of I. A. S. H., represented this Association within the Panel.

The recommendations made by the Panel were reported in our bulletin no. 4.

The Executive Committee of W. M. O. has just taken the following decisions (Resolution 6/EC-IX)

WMO PROGRAMME IN HYDROLOGY
(Final number: 6 (EC-IX))

The Executive Committee,

Noting

Résolution 24 (Cg-II),
Recommendation 1 (WR-I);

Decides

1. That the WMO Programme shall include the following items in those aspects of Hydrology which fall within the common ground of Meteorology and Hydrology:

a) The preparation of Technical Regulations in Hydrology;

b) The preparation of a Guide or Guides on international practices in Hydrology;

c) The development of international standards for:

(i) Hydrologic observations and networks, including hours of observation and the units used;

(ii) The routine exchange of hydrologic data and forecasts;

(iii) Codes to be used for this exchange where the data are required urgently, for example between countries having a common river;

(iv) Forms of hydrologic yearbooks;

d) The incorporation of special maps for the use of hydrologists in the World Climatic Atlas and in Regional Climatic Atlasse;

e) Collaboration with other organizations in the preparation and publication of a hydrologic terminology;

f) The preparation of Technical Notes on various aspects of Hydrology, for example, on methods used in hydrologic forecasting;

g) The organization of international symposia and training seminars;

2. That WMO shall continue to collaborate closely with the United Nations, the Specialized Agencies concerned and the International Association for Scientific Hydrology of the IUGG in all matters relating to Hydrology; and

REQUESTS the Panel on Water Resources Development to assist the Secretary-General in carrying out this programme; and

DIRECTS the Secretary-General

1. To communicate this Resolution to all concerned;

2. To implement the above programme insofar as available staff and resources permet.

The Resolution does not mention an additional decision, on the subject of the arrangement with our Association regarding the hydrological bibliography. The Secretary-General of W. M. O. has informed the Secretary of the Association that his Executive Committee has approved a grant of $ 500 in 1958, subject to the delivery to him of 105 copies of the national bibliographies which appear in the course of the year.

V. SYMPOSIUM SUR LA PHYSIQUE DU MOUVEMENT DE LA GLACE

Lors de l'Assemblée Générale de l'Association Internationale d'Hydrologie Scientifique à Toronto en septembre 1957, la Commission des Neiges et des Glaces avait proposé de tenir en 1958 un Symposium sur la dynamique de la glace. Cette proposition a été acceptée, compte tenu du succès remporté par les Symposia Darcy organisés par l'A. I. H. S. à Dijon en 1956.

L'A. I. H. S., et tout particulièrement la Commission des Neiges et des Glaces, ont décidé de tenir ce Symposium à Chamonix — Mont-Blanc (Haute-Savoie) France, du 16 au 24 septembre 1958.

Le Symposium sera consacré à l'étude d'un problème scientifique déterminé ayant une grande importance en Glaciologie. La confrontation des résultats des travaux des spécialistes intéressés et leur discussion se révélera certainement très fructueuse. Une telle manière de procéder n'est jamais possible lors d'une Assemblée Générale.

Le sujet proposé est le suivant :

LES ASPECTS PHYSIQUES DU MOUVEMENT DE LA GLACE

Il comprend aussi bien les causes et conditions que les particularités du mouvement lui-même, la thermodynamique de la glace sous toutes ses formes, les essais en laboratoire, les observations et mesures du mouvement des glaciers, calottes glaciaires et inlandsis polaires.

L'Association Internationale d'Hydrologie Scientifique fera son possible pour publier les communications présentées au Symposium avant la réunion.

Pour ce faire, vous devez envoyer en triple exemplaire vos communications prêtes à l'impression avant le *1er juin 1958* dernière limite à :

Monsieur le Professeur L. J. TISON
Secrétaire Général A. I. H. S.
61, rue des Ronces
GENTBRUGGE
Belgique

Les communications en français ou en anglais doivent être précédées d'un court résumé dans la langue de l'auteur plus une traduction dans une des deux langues officielles de l'Association. Les figures, cartes et schémas doivent être dessinés sur papier calque. Les auteurs sont priés de réduire au maximum les photographies à reproduire dans le texte, vu le coût prohibitif de leur reproduction.

Aucun volume des communications présentées au Symposium ne pourra être cédé à titre gratuit. Des tirés à part peuvent être obtenus à titre onéreux.

Frais d'inscription

Chaque participant au Symposium sera invité à verser à son arrivée à Chamonix au Comité d'organisation une somme de 2 $ (deux dollars) pour frais d'inscription.

Correspondance

Toute correspondance relative au Symposium devra obligatoirement être adressée à :

Monsieur le Professeur L. J. TISON
Secrétaire Général A. I. H. S.
61, rue des Ronces
GENTBRUGGE
Belgique

SYMPOSIUM ON PHYSICS OF ICE MOVEMENT

SYMPOSIUM, 1958

My dear colleague,

At the General Assembly of the International Association of Hydrology at Toronto in September 1957, the Commission on Snow and Ice proposed to hold a Symposium on Glacier Movement in 1958. This proposal has been accepted, taking account of the success achieved by the Symposium Darcy organised by the I A H at Dijon in 1956.

The I A H and in particular the Commission on Snow and Ice has decided to hold this Symposium at Chamonix — Mont Blanc (Haute-Savoie) France, from the 16th to 24th September 1958.

The Symposium will be devoted to a particular scientific problem of great importance to glaciology. The comparison of the results of the work of interested specialists and their discussion will be very fruitful. Such a procedure is never possible at a General Assembly.

The subject proposed is:

THE PHYSICS OF ICE MOVEMENT

This includes the causes and conditions as well as the detailed study of the movement itself, the thermodynamics of ice in all its forms, laboratory tests, observations and measurements of movement of glaciers, ice caps and polar inland ice.

The International Association of Hydrology will do its best to publish the papers presented to the Symposium before the meeting.

To do this you should send in triplicate your papers ready for printing before the limiting date of 1st June, 1958 to:

Monsieur le Professeur L. J. TISON
Secrétaire Général A. I. H. S.,
61 rue des Ronces,
GENTBRUGGE
Belgique.

The papers in French or in English should be preceded by a short resume in the author's own language, together with a translation into one of the two official languages of the Association. Maps and figures should be drawn on tracing paper. Authors are asked to reduce to a minimum the number of photographs to be included, in view of the prohibitive cost of reproduction.

No volume of the papers presented can be given free. Reprints will be obtainable for certain payments.

Registration Charge

Each participant in the Symposium on arrival at Chamonix will be asked to subscribe to the Committee of Organisation a sum of $ 2 (two dollars) for cost of registration.

Correspondence

All correspondence relating to the Symposium should be adressed to Professor Tison.

Monsieur le Professeur L. J. TISON
Secrétaire Général A. I. H. S.,
61, rue des Ronces
GENTBRUGGE
Belgium.

VI. RAPPORTS NATIONAUX PRÉSENTÉS A L'ASSEMBLÉE DE TORONTO

(suite)

SUDAN

NATIONAL REPORT ON HYDROLOGY TO 1957

Hydrological Records on the Nile and its Tributaries in the Republic of the Sudan

Sudan depends for its prosperity on water from the Nile and its tributaries. Without good hydrological records that water cannot be efficiently used. This report is therefore devoted to a brief description of the most important gauge sites. As each is mentioned for the first time the year from which records are continuously available is given in brackets. The use to which this information is being put is described in a paper presented to the Hydrological Section of this conference on planning the Nile Valley as a whole.

The lakes at the source of the White Nile (Bahr el Jebel) are not in Sudanese territory, but they are so important hydrologically that the principal gauges must be mentioned. The first of these is at Entebbe (1899) on Lake Victoria; there are a number of others round the lake, but this is usually taken to be the master gauge. The next important gauge is at Masindi Port (1915) where the main stream leaves Lake Kyoga. The master gauge on Lake Albert is at Butiaba (1912); readings began here early in 1904 but there were long interruptions in 1910 and 1911.

The first gauge in the Sudan is on the frontier at Nimule (1923). The series of rapids that starts here ends at Juba (1925) which is the most important town in the Southern Sudan. At Mongalla (1905) the river enters the great clay plain of the Upper Nile; from here on there are no effective tributaries until the confluence of the Sobat far to the north.

The Sudd Region proper can be considered to start at Bor (1906). The name is derived from the Arabic word for a block, and it is so called because before the days of regular navigation the channel was often blocked by masses of floating vegetation. From here on the river winds slowly through interminable papyrus marshes, and the losses due to spill are very heavy. Gauge readings here were interrupted for nearly a year in 1915-16.

It is intended to reduce spilling in the Sudd Region to negligible amounts by a bypass channel which will start at Jonglei and be known as the Jonglei Canal. For this reason the gauge at Jonglei (1931) is important. Travelling downstream, we come to Shambe (1904) which is a small village in the heart of the Sudd Region. About 120 kilometres further north the Bahr el Zeraf is fed through the Cuts (1927) which are parallel artificial channels with gauges at the head and tail.

The Sudd Region can be considered to end at Buffalo Cape (1927) on the Bahr el Jebel and Fangak (1924) on the Bahr el Zeraf. At Lake No (1924)

the Bahr el Ghazal joins the main stream, which is known from here to Khartoum as the White Nile. In spite of its large catchment area the Bahr el Ghazal makes a negligible contribution to the discharge of the White Nile. This is the result of very large losses in marshes to the west of the Bahr el Jebel. One day it will, no doubt, be possible to reduce these losses greatly. The problem has, however, not been studied in detail. The rivers concerned have very flat slopes in their lower reaches, and for this reason alone the solution will not be simple.

The most important gauge on the Bahr el Ghazal is at Wang Kai (1928) near the confluence of the Bahr el Arab. On the various tributaries the principal gauges are at Nyamlell (1934) on the Lol; at Wau (1907) on the Jur; at Tonj (1933) on the river of the same name; at Gel (1944) on the river of the same name; at Mvolo (1943) on the Na'am; and at Mundri (1943) and Yirol (1933). In general gauge stations in the catchment of the Bahr el Ghazal are much more sparsely distributed than on the main stream of the Nile.

About 120 kilometres east of Lake No the main stream receives the only tributary between Mongalla and Khartoum that makes a significant contribution to its discharge. The Sobat is formed by the confluence of the Pibor and the Baro on the Ethiopian frontier. Gambela (1906) is an important gauging point on the upper Baro in Ethiopia. The Pibor is formed at Pibor Post (1925) by the confluence of three rivers; later it is joined by the Akobo River at Akobo (1925). On the Sobat proper there are important gauges at Nasir (1923) and Doleib Hill (1904); the latter is often called Hillet Doleib.

Twenty kilometres or so from the Sobat confluence we reach Malakal (1905), which is the administrative capital of the Upper Nile Province. Between Malakal and Khartoum the principal gauges are at Kodok (1907) in the country of the Shilluk; at Melut (1907) and Renk (1907) in the country of the Dinka; at Rabak (1907) where the main railway line to the west crosses the White Nile a few kilometres south of Kosti, which is the largest river port in the Sudan; at Dueim (1907) in whose neighbourhood there are large numbers of pumps drawing water from the White Nile; and finally at Jebel Aulia (1915) where there is a storage dam across the river just over 40 kilometres south of Khartoum.

At Lake Tana, where the Blue Nile starts, gauge readings are available from 1921 to 1933 with a gap in 1926. Unfortunately no other gauge records have been published for the Ethiopian section of the Blue Nile. In the Sudan the first important gauge is at Roseires (1903); it is a few kilometres north of the site of the proposed storage dam for which plans are now almost ready. At Sennar (1907) the dam was finished over 30 years ago; it serves the double purpose of storing water and enabling the million-acre Gezira Irrigation Scheme to be commanded.

Between Sennar and Khartoum the Blue Nile receives the only two tributaries of any importance which join it in the Sudan. The first is the Dinder which is gauged at Abu Hashim (1907) and Hillet Idris (1924). The second is the Rahad which is gauged at Mafaza (1908 with gaps in 1911 and 1919) and Abu Haraz (1922); the latter is near Wad Medani (1907) which is the headquarters of the Sudan Irrigation Department.

At Khartoum (1900) the Blue and White Niles join to form the Main Nile, which does not receive a single tributary in its three-thousand-kilometre course to the Mediterranean Sea. It is believed to be the longest stretch of river in the world of which this can be said. Between Khartoum and the mouth of the Atbara River the most important gauge is at Hugna (1954); it is at the northern end of the 20-kilometre-long Sabaloka Gorge and near

a possible site for a power dam. The gauge at Shendi (1909) is important for basin irrigation in the district.

The town of Atbara (1908) lies at the confluence of Atbara River with the Main Nile. In the Sudan the river is gauged at El Showak (1937) and Khashm el Girba (1906). The headwaters are in Ethiopia, and unfortunately no gauge records have been published. The Setit, which joins the Atbara proper at El Showak, is in fact the main stream. It has recently been proposed to dam the Atbara at Khashm el Girba in order to irrigate by gravity an area of at least half a million acres to the north. The Atbara is not a perennial river, but no other affluent of the Main Nile carries water every year.

At Shereik (1954) the gauge marks the tail of the Fifth Cataract, which could be developed for hydro-electric power. At Abu Hamed (1909) the main line of the railway, which has followed the river since Khartoum, cuts straight across the desert to Wadi Halfa. A branch line follows the river to Merowe (1908) near which there is an excellent site for a dam which could be used either to store water or to generate power. From El Bauga to Merowe the river is constantly interrupted by cataracts, but a placid reach now begins and continues until Kerma.

At short distance south of Kerma there is a gauge at Argo (1909). Kerma itself marks the beginning of a series of cataracts which continues until Wadi Halfa. On this reach there are gauges at Dal (1954) and Semna (1954) both of which are promising power sites. The last gauge in the Sudan is at Wadi Halfa (1890). To complete this account it may be mentioned that the most important gauges in Egypt are at Aswan (1871) in Upper Egypt; Assiut (1903) in Middle Egypt; and El Leisi (1906) not far from Cairo. The first of these is near the site of the famous Aswan Dam.

This catalogue of gauges is by no means complete, but it will perhaps have sufficed to show how thoroughly the basin of the Nile is covered by a network of gauges in Uganda, Sudan and Egypt. At all important sites the gauges have been carefully calibrated by means of regular current-meter observations. Most of the gauges mentioned in this report were originally installed by the Egyptian Irrigation Department, which still continues to read them regularly and to compute discharges. The results are published in 'The Nile Basin' which is the standard work on the subject in eight volumes with various supplements.

Gauges up to 1927 are recorded in Volume III of 'The Nile Basin' and discharges up to the same date in Volume IV. Supplements, each covering five years, carry the published records forward to 1947. They give, for both gauges and discharges, ten-day, monthly, and annual means. The metric system is used throughout. For those who are interested in general information about the River Nile and its potentialities for irrigation the Ministry of Irrigation and Hydro-Electric Power in Khartoum has recently published a pamphlet on 'Sudan Irrigation' with twenty large pages and a complete set of maps.

ISRAEL

REPORT ON HYDROLOGICAL ACTIVITIES IN ISRAEL DURING THE YEARS 1954-1956

1. Hydrological Bodies

1. Hydrological routine investigation and/or research work in Israel is carried out mainly by the following bodies:

a. Hydrological Service, Water Authority, Ministry of Agriculture.

b. Department for Hydrological Planning, «Tahal», Water Planning for Israel, Ltd.

c. Soil Conservation Service, Water Authority Ministry of Agriculture.

d. Division of Hydraulic Engineering, Israel Institute of Technology, Haifa, Israel.

Besides bodies engaged in other activities have to do some hydrological studies, viz.:

Meteorological Service, Ministry of Transport and Communications.
Geological Institute, Jerusalem.
Weizmann Institute, Rehovot.
Department of Geology, Hebrew University, Jerusalem.
Private firms, e.g. Loehnberg & Loehnberg.

Detailed reports were presented by *a*), *b*) and *d*).

2. Activities of the Hydrological Service

These include:

a. Collection of data on: Water levels and salinity in observation wells; Water levels, discharge and chemical analyses in springs and gauging stations on rivers and wadis, mostly equipped with recording gauges. Recently most catchments have gauging stations and the data enable to describe the hydrological cycle in each catchment. floods including, as they have hydrographically and hydrometeorologically been analised in close cooperation with the Meteorological Service. The results were published in the Hydrological Yearbook for the years 1953/54, 1954/55. The Yearbook 1955/56 is under press. Unpublished data required by other bodies have been supplied to them, thus enabling their activities enumerated below.

b. Investigations on the hydrological cycle in relation to precipitations, in cooperation with the Meteorological Service, the Geological Institute, the Division of Hydraulic Engineering of the Israel Institute of Technology-Haifa, and the Department for Hydrological Planning of «Tahal». The results were presented as summary reports:

(1) Precipitation over and runoff from Jordan and Litani catchments (1955).

(2) Underground water in the Haifa-Acco sand dunes and its replenishment (1956; presented at the Darcy Symposium; Dijon), (vide also f 3*a*).

(3) Precipitation over and replenishment of the Yakon and Nahal Hatteninim underground catchment (under press).

These studies seem to lead for most watersheds towards an equation between mean yearly rainfall (P_o) and mean yearly surface runoff R over many years (in mm):

$$R = a(P - Po)$$

and for Haifa dunes:

$$R = bP + c$$

c. Effect of tides on the groundwater levels in the Coastal Plain and on the interface.

d. Two recording water-level gauges were developed by the workshop of the Hydrological Service.

e-g) Details, vide 3, *h-j*.

3. Activities of the Department for Hydrological Planning, «Tahal»

This department was established with the help of Prof. C. E. Jacob of Utah, U. S. A., who spent a year in Israel.

In the hills the following studies were conducted:

a. Studies of Nahal Hattanninim watershed: comparison of wadi and groundwater levels; comparison of hydrographs of active wells; chemical analyses and temperature of springs and wells; geological study. Results presented in Report: P. M. 20, May 1957. (Vide also 2, *b*(3)).

b. Groundwater replenishment tests in Lud area, to investigate underground storage of winter water of Ras-el-Ein springs. More than 1000 m^3/hr were injected into limestone and effects were felt at a distance of several kilometres. The effect of 10 tons of sodium chloride was not felt even after a long time.

c. Study of salinity in deep wells in the Negev and Hartuv Mountains: brackish water was found on top of sweet water without intervening impervious layer.

d. Statistical study of Yarqon River for forecasting (First report by M. Miro, No. 1173/9, Oct. 1956, Tel-Aviv).

e. Statistical study of Kurdanasprings; hydrogical study of Karkur area; geo-hydrological study of Western Galilee; hydrological watersheds in the Triangle, complementary to *a*); runoff studies in Menashe area. Reports under press.

f. Use of radioactive tracers for groundwater studies in cooperation with the Weizmann Institute. Report under press.

g. Yearly report on wells of the Mekorot Co. for 1955/56.

In the Coastal plain the following studies were conducted:

h. Water balance in strips normal to coast by numerical solution of Jacob's differential equation — at Migdal, Yavne, Giv'at Brener, Herzlia. No final conclusion reached.

i. Many pumping tests in order to find transmissivity and storativity of coastal aquifers; many observation wells for study of interface movements; survey of salinity of coastal wells; research on entrance of aquifer into sea; geological mapping of coastal plain in cooperation with Geological Institute; hydrological routine studies in Coastal area.

j. In cooperation with Mr. G. Santing of the Netherlands' Government Institute for Water Supply an intensive study was conducted of the water balance in the various sections of the Coastal area and its safe yield. This

included: soil and geological survey, equipotential maps and water balances for dry and wet periods and for many years, so as to determine storativity, transmissivity and natural replenishment from rainfall, and results compared with pumping tests; movement of sea water interface and the hydro-geological factors; study of artificial recharge of groundwater so as to stop sea-water encroachment. Results are summed up in Report P. M. 23, May 1957.

h—j have been carried out in close co-operation and jointly with the Hydrological Service. (vide 2, *e-g*).

4. Activities of Division of Hydraulic Engineering, Israel Institute of Technology Haifa

a. Study of basic hydrology was introduced into curriculum of 3rd year Civil Eng. and 4th year Agric. Eng.; of advanced and regional hydrology into 4th year Hydraulic Eng. Two graduates in hydrology (M. Sc. theses).

b. Construction of large electrolytic analogy tray electronically controlled for study of flownets through non-homogeneous soils and earthfill dams, (M. Sc. theses).

c. Unsteady seepage from storage reservoirs by means of large Hele-Shaw hydraulic analogy, in cooperation with the Department of Mining, Israel Institute of Technology, on behalf of «Tahal».

d. Small Watershed Studies — research conducted since 1952 on behalf of the Ford Foundation in cooperation with the Hydrological, Meteorological and Soil Conservation Services, and the F. A. O. experts Dr. W. C. Lowdermilk and D. B. Krimgold.

Meteorological and hydrological data were collected on three medium sub-catchments of W. Sorek watershed in the Jerusalem Corridor, in order to determine peak rates and total runoff. These were integrated into a nation-wide program of runoff studies on small watersheds, functioning since 1956.

Results summed up in Report: Small Watershed Studies by S. Irmay, Haifa, June 1956 (2 volumes).

e. Theoretical and experimental studies on extension of Darcy law to non-homogeneous, non-isotropic, unsaturated, cracked soils and unsteady flow. Results summed up in papers by S. Irmay:

(1) Electrical analogy method for solving problems of two-dimensional flow in non-homogeneous isotropic media (Abstr., Trans. 34th Ann. Meet. Am. Geophys. Union, Washington, 1953, p. 344-345).

(2) Saturated steady flow in non-homogeneous media and its applications to earth embankments, wells, drains (Proc. 3rd Intern. Conf. on Soil Mech. & Found Eng., Zurich, 1953, *8*, 14, p. 259-263; 6 figs; abstr. in Bull. Res. Council of Israel, Jerusalem, *2*, 4, March 1953, p. 425).

(3) On the hydraulic conductivity of unsaturated soils (Trans. Am. Geophys. Union, 35, 3, June 1954, p. 463-467; 1 fig.).

(4) Flow of liquids through cracked media (Proc. Meet. Israel Physical Soc., Rehovot; abstr. Bull. Res. Council of Israel, Jerusalem, *5A*, 1, Nov. 1955, p. 84).

(5) Experiments on the range of validity of Darcy's law and the appearance of turbulence in a filtering flow (in English & French; La Houille Blanche, *11*, 3, July-Aug. 1956, p. 419-421.)

(6) Extension of Darcy law to unsteady unsaturated flow through porous media (Proc. Symposia Darcy, Dijon, Sept. 1956, U. G. G. I. Intern. Assoc. Hydrol., *41*, p. 57-66; 5 figs).

f. New formula for rating current meters found on basis of 12 years of measurements; S. Irmay: Empirical rating formula for current meters (in English and French, La Houille Blanche, Grenoble, *9*, 4, July 1954, p. 461-465; 4 figs).

5. Miscellaneous

The Meteorological Service has modified Thornthwaite's bookkeeping method so as to compute runoff for intermittent Nahal Sorek. Dates of occurrences of runoff were determined from climatological data. Report by N. Rosenan: Comparison of measured storm water runoff in an intermittent river (wadi) near Jerusalem with computed water surplus based upon climatological data from Jerusalem (Proc. Symposia Darcy, Dijon, Sept. 1956, U. G. G. I., Intern. Assoc. Hydrol., *42*, p. 77-84; 1 fig.).

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PARTIE SCIENTIFIQUE

NUMBERS OF STREAM-GAGING STATIONS IN VARIOUS COUNTRIES WITH ANALYSIS OF THEIR DISTRIBUTION IN THE UNITED STATES

BY

W. B. LANGBEIN [1]

A list of the number of stream-gaging stations in several countries has been prepared through the courtesies of the respective national offices. The results are given in the accompanying table together with statistics on population density, and where available, on developed water power and irrigation. Except as noted, the numbers of stations refer only to those in current operation for measuring the flow of streams. The information might be considered generally applicable to the year 1955, although some data were gathered much earlier and some slightly later.

The canvass shows that many countries are active in stream gaging, although there is a rather wide range in the scale of activities. Some countries such as Libya and the three countries of the Indo-Chenese peninsula have not yet (1957) established stations for the regular and continuous measurement of river flow. A few countries operate more than four stations for each 1,000 square miles of area. Yet some countries, high in population density and industrial development, have relatively few records of the flow of streams. For example, in Great Britain there are only 1.4 gaging stations per 1,000 square miles, one of the lowest densities for a country of this importance. However, it is noted that the Surface Water Survey has plans to increase the number from the present 125 to 400 or 500 during the next 10 years, bringing the density into line with that in other countries of northern Europe.

Inspection of the table shows that the areal density of gaging stations varies with the population density although there is considerable irregularity in this regard, largely because of the very great difference in prevailing levels of economic development. Although, the statistics are of interest for judging the general intensity of stream gaging in any country in relation to other comparable countries, quantitative analysis of the international distribution of gaging stations does not appear feasible at this time. Such an analysis, however, can be made for the United States.

Factors affecting distribution of gaging stations in the United States

Stream-gaging records are being collected currently at about 6,600 locations in the United States. About 80 percent of the stations have recording water-stage registers. Including stations no longer maintained, some discharge

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records have been collected at 13,000 locations. The average length of record of the gages now operating is only about 15 years, but at 82 of these gages the records date back 50 years or more. These long records are fairly well distributed throughout the country.

The distribution of the stations over the country is highly variable. The highest densities are in the smaller eastern States. New Jersey heads the list with a density of 10.8 stations per 1,000 square miles. Nevada has the lowest density with only 0.5 station per 1,000 square miles. There is the interesting question as to what extent stream-gag ng stations have been established over the United States in response to such stimuli as population, irrigation, water power, and flood damages. Population represents several things. Foremost, it represents a source of tax for stream gaging; it also represents a need for water for domestic purposes, and to a less extent, for industrial purposes. With population there are attendant problems of pollution, flood damages, and other directly or indirectly associated factors, which are or become a basis for operation of gaging stations. Irrigation and water power create needs for stream-gaging data that are not necessarily indicated by the figures of population. An analysis was made of the distribution of gaging stations by States in relation to their respective population, irrigated acreage, and numbers of waterpower plants.

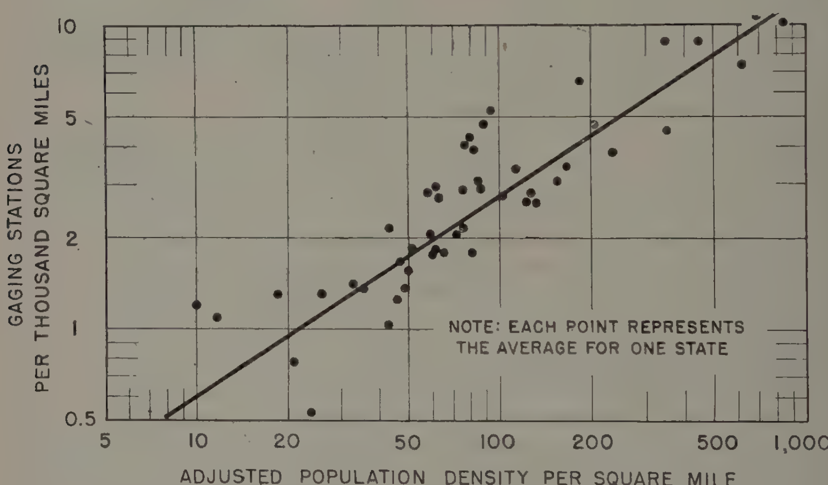

Fig. 1 — Number of gaging stations in the United States in relation to population.

Figure 1 shows the numbers of stations in each State per 1,000 square miles of area in relation to population density, as adjusted for irrigation and waterpower. The adjustments were determined by trial, their effectiveness being measured by the reduction and scatter of the plotted points. For the 17 arid western States where irrigation by diversion from streams is important, the population is increased by 4 for each irrigated acre. Thus, we might say that insofar as stream-gaging needs are concerned, each acre of irrigated farmland appears to be equivalent to 4 people. An adjustment was also made for waterpower. Here the analysis indicated each plant of 1,000 kilowatts or more capacity to be equivalent to 10,000 people. The relative influence

TABLE 1

Streamflow gaging stations in various countries

Country	Notes	Number of gaging stations	Area (1,000 sq. mi.)	Number of stations per 1,000 sq. mi.	Population per sq. mi.	Developed waterpower (horsepower per capita)	Irrigated area (acres per capita)
Afghanistan	(*a*)	20	245	0.08	48	.....	0.33
Argentina	(*aa*)	271	1,078	.25	17	.....	.135
Australia	(*b*)						
New South Wales		627	309	2.0	11	.....	.12
Queensland		196	670	.29	1.8	.....	.20
South Australia		66	380	.17	1.9	.....	....
Tasmania		76	26.2	2.9	11.7	1.8	....
Victoria		160	87.9	1.8	26.1	.....	....
Western Australia		43	975	.05	.61	.....	.91
Austria	(*c*)	300	32.4	9.1	218	.28	....
Brazil	(*aa*)	2,000	3,288	.61	17	.036	.006
Canada	(*d*)						
Alberta		91	248	.36	3.8	0.30	.77
British Columbia		350	359	.98	3.2	2.1	.034
Manitoba		47	220	.21	3.5	.90	....
New Brunswick		10	27	.37	19	.30	....
Newfoundland		14	37	.38	9.8	.90	....
Northwest Territory		14	1,253	.011	.013	.....	....
Nova Scotia		13	21	.62	30.6	.21	....
Ontario		168	363	.46	12.7	1.2	....
Prince Edward I.		0	2	0	49	.02	....
Quebec		181	524	.34	7.7	2.1	....
Saskatchewan		201	238	.84	3.5	.12	.078
Yukon Territory		27	205	.13	.044	.....	....

TABLE 1 (*continued*)

Streamflow gaging stations in various countries

Ceylon	(*e*)	77	25.3	3.0	325	.....	.077
Belgian Congo	(*ee*)	147	904	0.163	14.4	.05	....
Denmark	(*f*)	82	16.6	4.9	258	.004	....
Finland	(*g*)	190	130	1.46	31	.2	....
Formosa (Taiwan)	(*e*)	34	14	2.4	600	.....	....
France	(*h*)	675	213	3.1	200	.15	.14
Germany (West)	(*i*)	195	245	.80	180	.06	....
Great Britain	(*j*)	125	89.0	1.4	550	.01	....
India	(*e*)	302	1,222	.25	310	.002	.08
Iran	(*k*)	150	628	.24	31	.....	.25
Iraq	(*aa*)	30	172	.17	29	.....	1.6
Israel	(*l*)	85	7.8	11	190	.....	.074
Italy	(*m*)	489	116.2	4.2	406	.18	.10
Jamaica, BWI	(*n*)	24	4.5	5.33	300	.....	.035
Japan	(*o*)	807	147	5.5	573	.11	.10
Libya	(*aa*)	0	633	0	2	.....	....
Malaya	(*e*)	124	50.7	2.4	110	.....	.14
Mexico	(*p*)	450	760	.60	38	.03	.18
Norway	(*q*)	442	125.2	3.5	25.0	1.22	....
Pakistan	(*r*)	99	365	.27	208	.002	.28
Peru	(*aa*)	102	514	.20	17.5	.....	.35
Philippines	(*s*)	219	115	1.9	185	.....	.07
Poland	(*ss*)	325	120	2.7	220	.....	....
Sudan	(*t*)	50	969	.05	8.2	.....	.25
Sweden	(*u*)	330	173.4	1.9	38.1	.58	....
Switzerland	(*v*)	128	15.9	8.0	286	.82	.01
Thailand	(*w*)	30	200	.15	100	.....	.11
Turkey	(*x*)	261	296	.88	64	.0034	.01
United States	(*y*)	6,605	2,976	2.22	54	.18	.16
U. S. S. R. (European)	(*z*)	.....	.....	1.3	..	.....	....
U. S. S. R. (Total)		.....	8,200	.54	21	.....	....

of waterpower upon stream gaging was most prominent in New England, and in the northern States generally.

In general, the distribution of gaging stations is dominantly influenced by population density, with secondary influences of irrigation and waterpower. This observation probably applies internationally, with the important qualification that the influence of population depends greatly on the level of economic development.

NOTES

Number of gaging stations furnished by source shown; data on area, population, waterpower, and irrigation from Encyclopedia Britannica; Statistical Yearbook of the World Power Conference; and Irrigation in the World, by N. D. Gulhati.

(*a*) 15 stations are in Helmand River basin.

(*aa*) From unofficial sources.

(*b*) Australia.
New South Wales: Stations operated by several authorities; information furnished by Water Conservation and Irrigation Commission. No breakdown between stations where only water levels are measured and those where discharges are recorded; includes 89 stations in or near tidal sections of coastal river systems.
Queensland: Information furnished by Irrigation and Water Supply Commission; 178 stations in addition are read occasionally during floods.
South Australia: Information furnished by Engineering and Water Supply Department; 60 stations are intermittent.
Tasmania: Information furnished by Hydro-Electric Commission.
Victoria: Information from «Availability of hydrologic data in Victoria,» by K. D. Green, Jour. Inst. of Engineers of Australia, September 1954.
Western Australia: Information furnished by Public Works Dept.; 35 recording gages; 8 staff gages.

(*c*) Austria: Information furnished by Werner Kresser, Hydrographisches Zentralburo; plus 400 stage-only stations.

(*d*) Canada: Stations operated by or reported to the Water Resources Division, Department of Northern Affairs and National Resources; a considerable number of those in Saskatchewan, Alberta, and British Columbia are seasonal stations on drainage canals and ditches. Some additional stations are operated by provincial authorities or others.

(*e*) Ceylon: Number of gaging stations obtained from Economic Commission for Asia and the Far East.

(*ee*) Belgian Congo: Information furnished by E. Devroey. Secrétaire de l'Académie Coloniale, Brussels.

(*f*) Denmark: Information furnished by J. M. Lyshede, Detdanske, Hedesel kob.

(*g*) Finland: Information furnished by Allan Siren, Director, Hydrografinen Toismisto; plus 405 stage-only stations.

(*h*) France: Inormation furnished by L. Serra, Electricité de France. 501 are ordinary stations, 174 are power-plant records.

(*i*) West Germany: Information furnished by W. Friedrich, Bundesanstalt für Gewasserkunde; plus 927 stage-only stations.

(*j*) Great Britain: Information furnished by A. G. Bouton, Superintendent, Surface Water Survey.

(*k*) Iran: 200 stations planned.
(*l*) Israel: Information furnished by Martin Goldschmidt, Director, Hydrological Service.
(*m*) Italy: Information furnished by P. Frosini, Consiglio Superiore di Lavori Pubblici; 381 are recording stations, 108 staff-gage stations.
(*n*) Jamaica: Information furnished by C. C. Yonker, U. S. Geological Survey.
(*o*) Japan: Information furnished by Economic Planning Board; stations operated by River Bureau, 388; Public Utility Bureau, 30; Agricultural Land Bureau, 70; power companies and others, 319.
(*p*) Mexico: Am. Soc. Civil Engineers Trans., v. 116, p. 1205-1206, 1951.
(*q*) Norway: Information furnished by R. Sognen Norges Vassdrags-Og. Elektrisitsvesen; plus 174 stage-only stations.
(*r*) Pakistan: Information from Economic Comm. for Asia and the Far East.
(*s*) Philippines: Information obtained from reports of Economic Commission for Asia and the Far East.
(*ss*) Poland: Information furnished by Prof. J. Lambor, Service Météorologique et Hydrologique. Plus 875 stage-stations with irregular measurement of the discharge.
(*t*) Sudan: National Report on Scientific Hydrology to 1957, submitted to the Association of Scientific Hydrology, Toronto, September 1957.
(*u*) Sweden: Information furnished by R. Melin, Seveiges Meteor, Och Hydrologiska Institute. Plus 260 stage-only stations, 170 records of water temperature, 1,900 records of ice thickness.
(*v*) Switzerland: Information furnished by Emil Walser, Federal Service des Eaux.
(*w*) Thailand: Information from reports of Economic Commission for Asia and the Far East.
(*x*) Turkey: Elektrik Isleri Etut Idaresi, «Flow results of water-year 1955.»
(*y*) United States: Information furnished by U. S. Geological Survey.
(*z*) U. S. S. R.: «Hydrology in the U. S. S. R.», Am. Geophys. Union Trans., v. 24, p. 737-742, 1943.

EXPLORATORY DRILLING FOR GROUNDWATER IN THE NARMADA VALLEY, MADHYA PRADESH, INDIA

BY

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Geological Survey of India

I. General

With a view to assess the groundwater potentialities by conducting systematic studies of the groundwater conditions in different parts of the country the Government of India have lately launched the Groundwater Exploration Project under a Technical Co-operation Agreement with the Government of the United States of America. The principal object of this programme is to explore the possibilities of tube-wells in 16 different areas in the country by drilling more than 350 deep exploratory boreholes so that the geological and hydrological conditions of the areas concerned could be studied and their groundwater development potentialities evaluated.

Narmada Valley is the first region in India where the project commenced its work. The area explored covering 5000 square miles, includes parts of both Madhya Pradesh and former Bhopal State, and is shown on Survey of India topographic map Nos. 55 F, J, I, M and N on the scale of 1 inch = 4 miles. During the period of exploratory drilling, between January, 1955 and May, 1956, a total of 44 boreholes was drilled, of which those at 11 sites encountered materials considered not likely to be capable of yielding water in economic quantity. Of those, that penetrated water yielding formation production wells were completed at 16 sites.

Pre-drilling investigation and near surface ground-water studies were begun as early as 1953. The latter studies are being continued at present. Previous to the completion of exploratory drilling operation nothing was known regarding the actual groundwater potentialities of this region. It was a virgin area and no deep holes for groundwater extraction was ever attempted in this basin. The task of initial selection of sites for drilling, collection of geological and hydrological data and delineation of likely areas for groundwater development were entrusted to the Geological Survey of India. The actual drilling activities and all phases of exploratory well construction work were undertaken by the Exploratory Tubewells Organisation, Ministry of Agriculture, Government of India.

II. Physical Features

The alluvial stretch of the Narmada basin covers an area of about 5000 square miles, commencing from west of Jabalpur to east of Handia (76°58' : 22°29), a distance of about 200 miles. The width of the valley is variable between 15 and 30 miles. The valley on the south is bounded by the escarpments of the Satpura Range rising to heights of about 2000 feet above the M. S. L. The maximum height of the Satpura Range is reached by the summit of Mahadeo massif (4454 feet) in the Pachmarhi Hills. The general

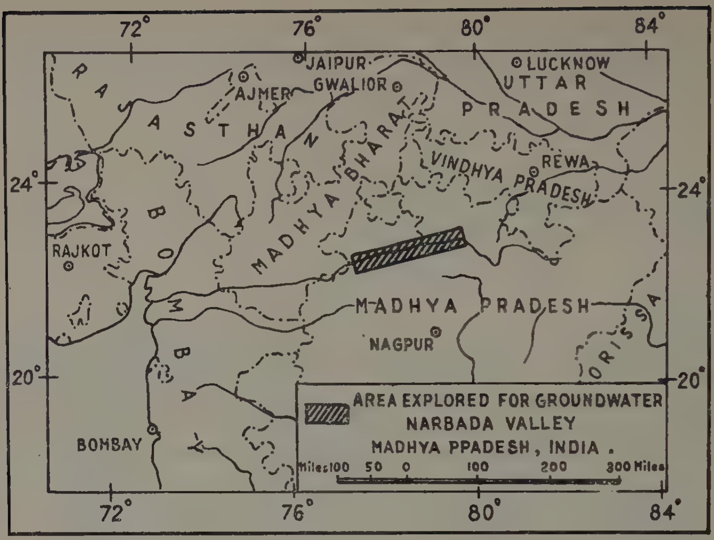


Fig. 1

elevation of the Narmada plains varies between 900 and 1200 feet from the sea level. The country slopes gently towards west in about three feet per mile. The drop in the level of the bed of the Narmada river between Jabalpur and Hoshangabad is 340 feet within a distance of about 120 miles. To the north of the valley rising almost abruptly from the plains are the ranges of Bhanrer, Kaimur and Bhitrigarh belonging to the Vindhyan Mountains. The hills range in height between 2000 feet and 2500 feet above sea level.

The Narmada basin is of the nature of rift valley caused by the down faulting of the rock formations on both sides along the base of the Satpuras and the Vindhyans. The resulting through is filled in by the materials carried down by the drainage emanating from the hills.

The alluvial plains of the Narmada basin is more or less a flat expanse of richly cultivated wheat land with slight undulations between the many tributary streams flowing across it. Besides cultivation the area shows good amount of green vegetation. The isolated knolls and low stony ranges are not infrequent in the plains.

Drainage:

The valley is drained principally by the Narmada River and its numerous tributaries all rising out of the hills chiefly from the south. The Narmada itself is a mighty river, flowing between steep well-defined banks. Very often during the monsoon floods the deep channel runs full to the brim. The Narmada river rises on the summit of Amarkantak (22°40′ N and 81°46′ E) at the north-eastern apex of the Satpura Range in Rewah (Vindhya Pradesh) and enters the sea below Broach in Bombay Presidency parsuing a westerly course for a total distance of about 800 miles. It enters the fertile alluvial land of Narmada Valley, emerging from the gorge known as «Marble Rocks» about

12 miles W of Jabalpur. It takes a westerly course through this alluvial tract, situated between the Satpura and the Vindhya hills. The valley has a width of about 20 miles on the south of the river. The Vindhyan hills rise in the form of sheer cliffs within 8-10 miles from the north bank of the river.

The principal tributaries of the Narmada rise in the Satpura hills to the south. They are the Sher and Shakkar in Narshingpur, the Tawa and Ganjal in Hoshangabad, and the Gaur in Jabalpur. The only important tributary on the north is the Hiran, which emanates from the Vindhya hills in Jabalpur district. Most of these tributaries have short and precipitous course from the hills.

During the rains the Narmada river is turbulent and is often in high spate, sometimes devastating, encroaching far inland on both the banks. The flood line varies between 0 foot to 88 feet from the bed level of the river. The maximum height attained in 1926, was R. L. 1263, near Jabalpur where the bed level of the river is 1175 R. L. During this flood the surface velocity of the river water reached 10-13 feet per second. The maximum flood discharge estimated was 1,83,500 cusecs. The normal H. F. L. of the river reached at least once every year is R. L. 1230 at Jabalpur.

Climate:

The climate of the basin as a whole is generally healthy. The cold weather, which lasts from the end of October to the end of February is remarkable for bright cloudless days and cool nights. The average maximum and minimum temperature in the month of January in the plains are 80.3°F and 52.3°F, respectively.

The hot weather begins from March and continues to the end of the June. During the day time the summer heat is oppressive, when the temperature very often shoots up above 110° F. The maximum temperature recorded at Hoshangabad was 118.5° F on the 1st June, 1844. The summer nights are pleasant and cool, because of the continuous evaporation of the moisture which is retained in the black cotton soil.

Rainfall:

The rainfall in the Narmada Valley as a whole is quite satisfactory. It varies from place to place. About 92 percent of the average annual rainfall occurs within the monsoon period, which usually breaks by the middle of June and continues till the middle of October. In the plains the average annual rainfall is about 47 inches. In the hills the annual precipitation is high. The average annual rainfall recorded at Pachmarhi is 77 inches.

Vegetation:

The Narmada Valley bears good vegetation all the year round. In the plains shady trees, Bar, Pipal etc. abound. Mango groves are frequently seen. The hills slopes specially the Satpuras show profusion of Sal (Shorea-robusta) and Anjan (Hardwickia Binata).

III. Geological Formations and their Water Bearing Capacities

The following is the geological succession met with in the valley:

1. Soil and Alluvium — Gravel, Sand, Silt, Clay etc.
2. Laterite — Ferruginous and pisolitic.
3. Deccan trap — Sills, flows, dykes and
4. Gondwanas — Sandstones and shales.
5. Vindhyan sandstones — Indurated compact flaggy sandstones.
6. Crystalline and Metamorphics — Granites, gneiss, quartzite, marble schists etc.

Crystallines and Metamorphics:

The rocks belonging to the crystallines and metamorphics do not occur in great force in the area under consideration. In the Hoshangabad district they are confined as narrow belts along the northern slopes of the Satpuras, viz. south of Itarsi (77°46′ : 22°37′), at Bagraj 3 miles E of Fatehpur and near Lokhartalai (77°27′ : 22°18′). In the beds of Narmada R. north of Narshingpur (79°11′ : 22°56′) and also near Harda quartzites, limestone and phyllites are the predominant rocks. At Bheraghat, 13 miles west of Jabalpur, the main rocks exposed are marbles and schists. Granites and granite gneisses constitute the hill known as «Madan Mahal», 4 miles NW of Jabalpur.

The crystallines and the metamorphics are not good water yielders. Limited quantities of water are available in the weathered zone, in fissures, cracks, joint planes etc. The texture of the rocks precludes the possibility of extracting groundwater on a large scale by means of tubewells.

Vindhyan Sandstones:

Rocks of the Vindhyan formations are restricted to the north of the valley. They constitute high ranges of hills rising abruptly from very near the bed of the Narmada river. Small exposures of Vindhyan rocks are occassionally met with jutting out of the plains viz. in the vicinity of Hoshangabad (77°45′ : 22°45′), Khaparia (77°50′ : 22°42′) and Sontalai (77°55′ : 22°40′). The commonest rock in these beds is a hard, compact fine grained, purplish, rather thin bedded, sandstones. Flagstone and good ballast are obtained from the quarries of Hoshangabad.

Vindhyan sandstones, because of their compactness and fine grained nature, are considered useless for ample storage of groundwater.

Gondwanas:

Rocks of Gondwana system occur in great force in the Satpura slopes along the southern edge of the Narmada Valley. They also have extensive distribution in the Satpura Range proper. The total thickness of Gondwana sediment in this region is estimated at 10,000 feet. Along the scarps, where they are overlain by Deccan traps, the Gondwanas are more or less horizontal with gentle dip varying between north and north-east. Both lower and upper Gondwanas are well exposed in the region, which principally consist of conglomerates, sandstones, clays and occasional limestones. The sandstones and conglomerates are the predominant rocks in the lower Gondwanas. From Sali (near Nandarwara 77°37′ : 22°28′) to Lokhar talai (77°25′ : 20°22′)

and between Mohpani (78°50′ : 22°45′) and Sadnapur (79°02′ : 22°47′) there are well defined scarped edges of conglomerates and sandstones. In the Jabalpur district the upper Gondwanas (Jabalpur group) are mostly represented, where they consist principally of clays, shales and clayey sandstones with thin beds of coal and carbonaceous shales. The sandstones are generally coarse and conglomeratic.

The Gondwanas specially the sandstones and the conglomerates are good water yielders. Unfortunately the distribution of these rocks are mostly in the hill slopes, where the disposition of the beds is not conducive to large storage of groundwater. No outcrops of Gondwanas are seen in the Narmada plains proper. During the course of the exploratory drilling, Gondwana rocks (Denwa clay) were encountered in some of the holes, but nowhere they were sandstones.

At Jabalpur there is a good exposure of Gandwana sandstones which form a sort of a basin of considerable size. This basin is saturated with water and is extensively used for groundwater extraction. The M. E. S. Jabalpur have got their water works at Pachpedi (79°49′ : 23°8′) wherein 8 tubewells are working. The yield out of individual tubewells here varies between 5,000-12,000 gallons per hour. The daily consumption from their water works is 800,000 gallons. The tubewells vary in depth between 150 and 300 feet and in diameter between 8 and 10 inches. All the tubewells, excepting one, are unlined, and no strainers are being used. The water level in the boreholes varies between 27 feet and 48 feet from the surface.

Deccan trap:

Rocks of the Deccan trap series like other hard rocks in the area are confined to the hills, along the southern edge of the valley. They are unreliable yielders of water. They are massive, tough and increasingly difficult to penetrate with depth. In the Deccan trap basalts water occurs only in joint planes, and in the vesicular and fragmental material or inter-trappean beds lying in between successive flows. Some water might be available in the residual soil capping and in the upper weathered zone, but the supply from this is, however, limited. In general, the possibilities of large scale extraction of groundwater from the trap formations might be ruled out.

Laterite:

Laterite occurs as small patches in the area under description. The areas where they have been encountered in the valley are (i) half-a-mile east of Sontalai village and (ii) at the river bed in Dolaria village. In view of their meagre distribution in the area, the question of their suitability for large scale extraction of groundwater does not arise.

Alluvium:

The Narmada plains is covered by alluvial materials consisting of stiff reddish, yellowish or brownish clay with numerous intercalated bands of sand and gravel. Kankar is present in abundance in the alluvium and pisolitic iron-ore granules are not infrequent. The alluvial materials have been derived from the washing of the hill slopes through the agencies of numerous streams and water courses emanating from the hills. The thickness of the alluvium is variable depending upon the floor of the basin of deposition which is uneven,

as is evident from the occasional jutting out of the underlying rocks in the plains. The constituents and the nature of the alluvium vary locally, depending upon the rock composition in the catchment of the area from where they are derived, e.g. north of the hill ranges of Pachmarhi where the predominating rocks are sandstone, the alluvium is predominant in sands and sandy materials. Whereas, the area which receives washings from the Deccan trap and the Gondwana shales and clay, the alluvium is predominantly clayey.

The results of the exploratory drilling indicate that in the western portion of the area, Pawarkheda-Dharamkundi-Pagdhal tract, the alluvium is shallow varying between 78 and 208 feet. In the central portion of the valley, alluvial fill is tick and is of the order of 400-700 feet. On the north bank of the river in the Bhopal and Jabalpur areas, the thickness of the alluvium ranges between 100 and 350 feet.

The groundwater level in the valley gradually lowers down as one approaches from the hills towards the Narmada river. In the areas near the base of the hills the water level varies between 10 and 15 feet from the ground surface. In the areas midway between the hills and the river the water level is between 30 and 40 feet whereas in the villages situated near the bank of the Narmada river water level is as low as 50 to 70 feet from the ground surface. This shows that the Narmada is of effluent type and receives ample seepage of groundwater during its journey through that part of the valley which is under report. Plate 1 (prepared by the writer and his colleague Mr. D. V. Ramanamusty), shows the water table contours and the areal distribution of the rock formation in the typical area, Gadarwara-Piparia-Narshinghpur region of the basin.

IV. Location of Sites for Exploratory Drilling

The sites for drilling were located on geological considerations namely in areas where greater thickness of alluvium could reasonably be surmised. Greater the thickness of alluvial fill more are the chances of striking sand and gravel beds which are likely to be prolific aquifers. At the first instance a tentative selection of sites were made at vantage points along and across the valley. This was followed up by a geophysical investigation, whereby the probable thickness of the alluvium at the individual sites were ascertained. In the Narmada Valley it was not found necessary to reject any of the tentative sites on the basis of geophysical results. The geophysical soundings tallied well with the general estimation of depths down to bed rock based on the study of the surface geology.

In final pin-pointing the sites for drilling particular care was taken to fix them wherever possible by the side of all weather motorable roads so as to facilitate easy movement of heavy drilling equipment. As it was anticipated that a good number of the exploratory wells would be converted into production wells, the sites were so located that they were at higher level than the surrounding country and would easily command 300-400 acres of land — a block which an one cusec well can fairly irrigate and thus could be put into use forthwith for irrigation purposes.

V. Drilling Equipment used

To carry out the drilling activities in the valley five rigs were put under operation. Of these two were Failing 1500 one Star Rig, designed to operate both as a rotary and cable tool rig, one Senior May-Hew Rig — capable of drilling pilot holes down to 1000 feet only and one Winter Weiss Reverse Circulation rotary rig. All the drilling was of rotary type. Other necessary equipment e.g. Air Compressors for development of aquifers and turbine pump sets for aquifer performance tests were employed. The turbine pump sets were of Layne and Bowler make and 8 inches in size. The compressor included Le Roy and Atlas make. Besides these, water tankers, motor transports etc. were also available.

VI. Drilling Procedures

In the Narmada Valley, as it was anticipated that unconsolidated or semi-consolidated rocks will have to be tapped only for groundwater extraction straight rotary method of drilling was adopted. In this method drilling mud, which is a mixture of suitable proportion of bentonite (clay) and water, is used. This prevents caving of the holes and also brings up the drill cuttings easily to the surface along with the return mud.

To start with pilot bore was drilled first at the individual sites in this valley with a 5 5/8 inch drag bit or rock roller bit, through the entire thickness of the soft rock. The hole ended in bed rock, i.e. hard or impervious rock below which further water bearing materials are not likely to be encountered. Out of the 44 holes sunk in the valley 27 reached the hard basement rock which constitute the Narmada alluvial basin.

During the progress of drilling, cuttings coming out along with the return mud at regular intervals of 10 feet and/or at every formation change, were collected and examined. Continuous record of drilling time, nature of drilling action, hydraulic pressure employed etc. were kept. The geologists had to be present at the site in shifts round the clock to observe the progress of drilling and record the above data. After the drilling of the pilot hole was completed down to the required depth, electrical logging of the hole with the help of an instrument called Electrical Logger was done. This operation measured the electrical properties of the different formations encountered in the hole. The Logger consists of a sensitive electronic machine where in a graph is automatically recorded showing the resistance and the self potential of different strata encountered in the hole by allowing an electrode to traverse along the section of the hole. Proper interpretation of these logs helps to determine the lithological character and porosity of the strata and also to ascertain the likely chemical quality of water contained in the aquifer.

Simultaneously, as the drilling progressed the cuttings collected at the site were sent to the field laboratory and examined for likely water bearing materials. Mechanical analysis of the aquifer materials whenever necessary were undertaken to ascertain the screen sizes and the sizes of the gravel to be required for shrouding fro construction of production wells.

From the results of the study of drill cuttings and the interpretation of the electrical log a strata chart is prepared.

VII. Exploratory well Construction

Having known now the nature of the aquifer materials and the zones to be tapped in the hole section, action is taken to convert the pilot hole into an exploratory-cum-production well. The hole is reamed to a large diameter, usually from 9 7/8 to 20 inches and 6-10-inch perforated casing installed in the aquifer zones. If the data obtained from the initial pilot hole indicate that the strata encountered are unlikely to yield considerable water, the particular hole is abandoned.

After the hole is reamed to a large diameter and the casing with perforated sections at required depths are installed, the annular space between the casing and the wall of the enlarged hole is packed with properly graded gravel. This operation is called gravel packing. The gravel shroud minimises the flow of finer materials into the screen and helps to increase the specific capacity of the well. The average size of the gravel to be used depends upon the average size of the aquifer materials encountered.

On completion of the gravel packing operation, the well is now developed with air compressor. This consists of surging the well up and down with compressed air to break and remove the mud plaster in the wall of the hole and to make certain the aquifers are open to the well. Development of the well is deemed to be attained when the water coming out of the well is clear of mud and sand. The whole operation usually takes 6-10 hours and within about 24 hours usually the water in the well attains the static level, exact measurement of which is very important in carrying out tests concerning the hydraulics of a well.

VIII. Hydrological Tests

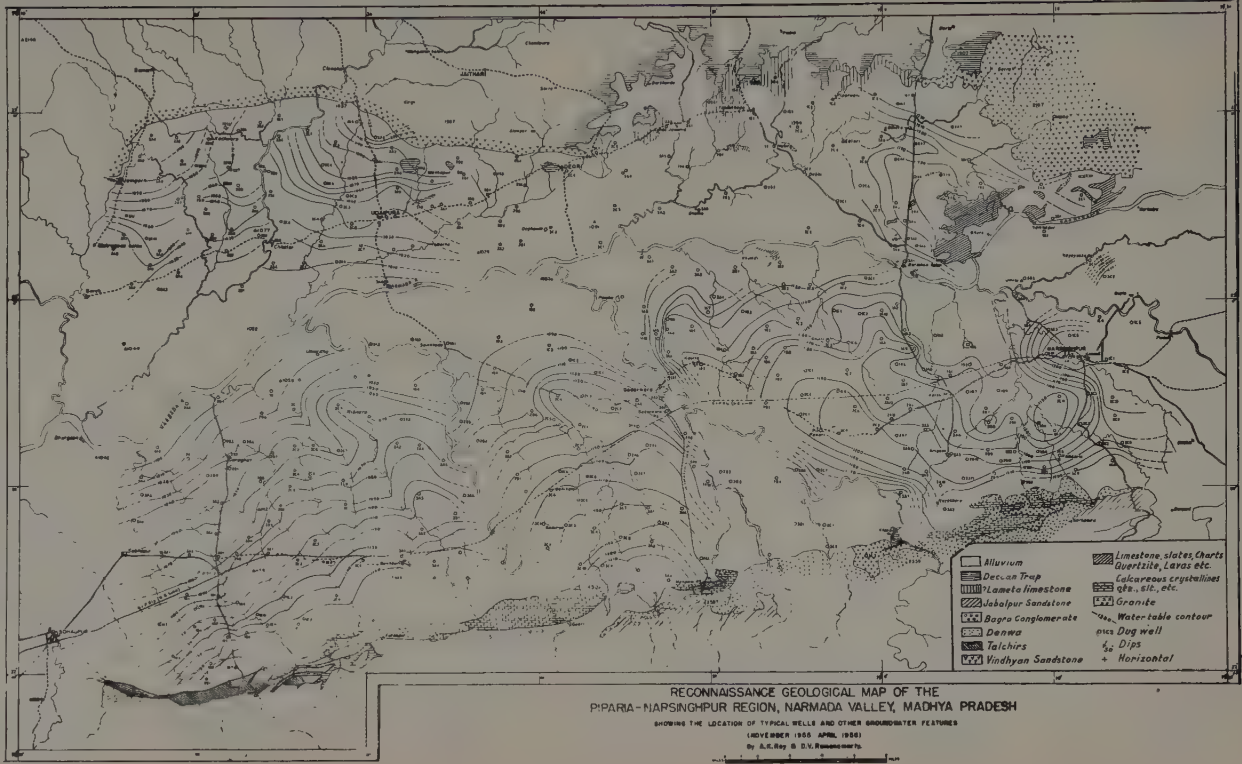
The well is now ready for final pumping test. A vertical turbine pump is lowered into the well to a depth depending upon the static water level and the expected drawdown. During the pumping which is usually of 6 to 10 hours duration, drawdown and discharge are measured and water samples ares collected. Recuperation level measurements are recorded after the pump is stopped. The whole process is a highly technical job, and requires precise and skilled handling. From the data obtained during the actual tests computations are done to determine the specific capacity of the well, the transmissibility and permeability of the aquifer tapped. The permeability is the measure of capability of an aquifer to transmit water and is expressed in gallons per day per square foot, under a hydraulic gradient of 100 per cent. The greater the number the more permeable the material is. The transmissibility is the amount of water expressed in gallons per foot per day passing through the entire section of an aquifer under 100 per cent hydraulic gradient.

T is determined from the formula

$$T = \frac{264\ Q \log t/t'}{S}$$

where Q is the quantity of water pumped in gallons per minute, t is the time since pump started and t' is elapsed time since pump stopped. S indicates the amount of residual drawdown and is ascertained from a log distance intercept by plotting the t/t' values against S in a semi log graph paper. P is calculated by dividing the T value by the total thickness of the aquifer tapped.

In the Narmada Valley, pumping tests were conducted on 16 wells.



RECONNAISSANCE GEOLOGICAL MAP OF THE
PIPARIA-NARSINGHPUR REGION, NARMADA VALLEY, MADHYA PRADESH
SHOWING THE LOCATION OF TYPICAL WELLS AND OTHER GROUNDWATER FEATURES

The specific capacity of the wells varied between 9 and 59 gallons per foot of drawdown. The permeability computed for the wells ranged from 500 to 2400 gallons per day per square foot. The average thickness of the aquifer material tapped in the Narmada Valley is 100 feet. Table showing the yield and drawdown figures of 16 production wells completed in the Narmada Valley is appended.

IX. Recommended Areas for Groundwater Development

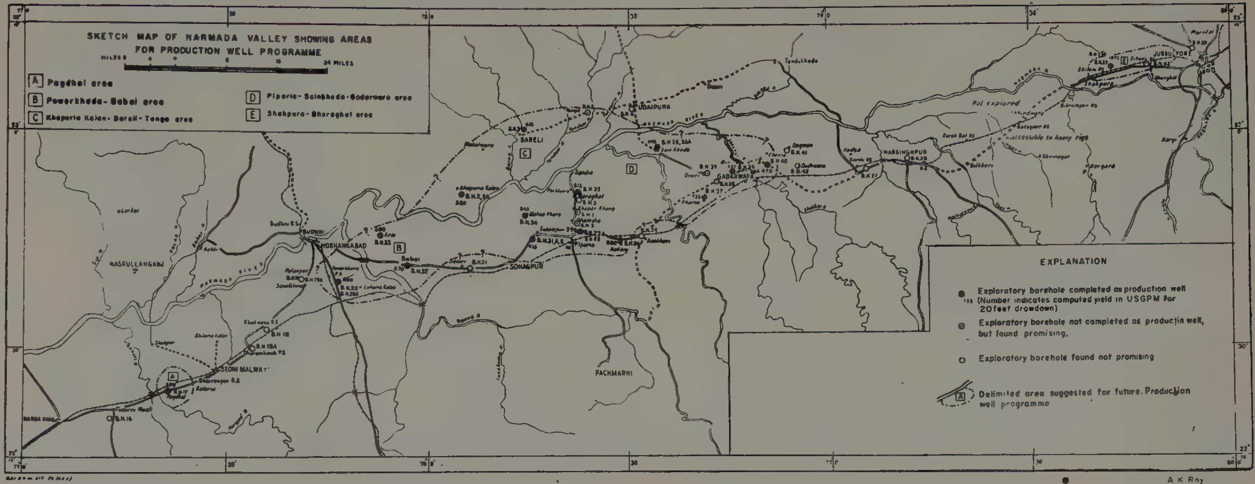
The over-all alluvial tract which has been found to contain good aquifers has been divided arbitrarily into 5 areas (*Plate I*), of which only two (see sketch map) are north of the river, one in Raisen Dist., Bhopal (area C) and the other in Jabalpur District, Madhya Pradesh (area E). The remaining three areas (A, B & D) are located in the Hoshangabad District, Madhya Pradesh, south of the river. The three areas B, C & D are grouped in one zone.

The five areas represent an aggregate of 560,000 acres south of the river and 220,000 acres to the north, all of which may be considered promising for the production of groundwater. On the map (*Plate II*) all five areas are enclosed by a boundary (three of the areas B, C & D being enclosed within one boundary line as stated above) which are intended to show, very approximately, the limit beyond which tubewells are not likely to have a yield great enough to be of economic value for large scale irrigation purposes. As shown on the map, large sections of the boundaries are approximate. They may, however, be established more firmly only by the drilling of additional test-wells. Even where the boundary has been fairly well defined, it should not be considered as strictly rigid although its existing position has resulted from intensive study of all of the available field information and, in general, should be reasonably valid. The five areas are discussed below.

Area A, Pagdhal area: The Pagdhal area is delimited on the basis of only one well, 220 feet deep, tapping an aggregate of 86 feet of aquifer. The yield during test was 470 gpm with a drawdown of 13.40 feet from a static level of 47.60 feet below land surface. The Pagdhal of which the boundary as shown on the map is very approximate, is roughly circular with the existing exploratory well 1½ miles SW of the centre. This eccentricity results from the occurrence of a basaltic rock outcrop in the bed of Gunjal river, which is about 3 miles west of the Pagdhal well and which, inferentially at least, would reduce the probability of finding an adequate thickness of alluvial materials in that direction. At least initially development of groundwater in area A should hence be started north and north-east from the existing well. The diameter of the area of suggested development is about 5 miles. The south-western arc of this circular area more or less coincides with the trend of the Morand River. To the east it extends to village Bilaria.

Area B — Powerkheda-Babai area : The area covering about 235 square miles is roughly elliptical in shape, and is bounded on the north by the rock outcrops of Hoshangabad and the Narmada River and on the south roughly by the railway line. The western limit passes about midway between Powerkhera and Samalkhera, and to the east the area merges into area D along an arbitrary line running north and south half way between Semri and Babai. The area is separated from area C by the Narmada River. The River Tawa forms the main drainage system of this area.

PLATE-II.


SKETCH MAP OF NARMADA VALLEY SHOWING AREAS
FOR PRODUCTION WELL PROGRAMME
MILES 0 4 8 16 24 MILES
A Pagdhal area
B Powarkheda-Babai area
C Khaparia Kalan-Bareli-Tonga area
D Piparia-Sainkheda-Gadarwara area
E Shahpura-Bhareghat area
EXPLANATION
Exploratory borehole completed as production well (Number indicates computed yield in USGPM for 20 feet drowdown)
Exploratory borehole not completed as productin well, but found promising.
Exploratory borehole found not promising
Delimited area suggested for future. Production well programme
HOSHANGABAD
SOHAGPUR
BARELI
UDAIPURA
GADARWARA
NARSINGHPUR
JUBBULPORE
PACHMARHI
NASRULLAHGANJ
SEONI MALWA
BUDHNI
A K Roy

Based on the evidence of three exploratory boreholes water levels range from about 22 to 50 feet below the land surface. All the three test-wells yield copious quantities of water materially beyond the minimum reported requirement. Although the thickness of the water-bearing materials at Powerkhera is small, of the order of 23 feet, the yield is prolific. With an aquifer thickness 77 feet at Ari and 137 feet at Babai, there is every possibility of striking prolific aquifers throughout most of this area within a depth of 300 feet below the land surface, except in the Powerkheda region, where bed rock might be encountered at a considerably shallower depth.

Area C — Kkapuria Kalan-Bareli-Tonga area (*Bhopal*): The area is roughly semi-elliptical. The Narmada river is the southern margin and the northern boundary runs like an arc from about two miles west of Khapuria Kalan, along the fringe of the Vindhyan uplands on the north (within two miles of the latter) and passes midway between Tonga and Udaipura, ending at the river to the SE of Tonga. Four pilot boreholes had been drilled in this area of which two were converted into production wells. One of the 4 wells, at Tonga, was pump-tested after the installation of a temporary casing. The yield obtained from the well suggested the existence of fairly prolific aquifer although the well was not converted into a production well. The maximum depth of water-yielding zones below the land surface in area C is expected to vary from 200 to 250 feet. Discharge from the wells was computed to vary from 366 to 625 USgpm for a drawdown of 20 feet. Static water-level varies from 30 to 40 feet, subject to seasonal fluctuation.

Area D — Piparia-Sainkheda-Gadarwara area: Area D is a roughly elongated area with irregular boundary extending from Mahuakhera and Sobhapur on the west of Kauria on the east; the Narmada river marks the northern limit and the tangible trace of the southern boundary lies roughly along the Central Railway Track. Around Bankheri, the boundary has wedged in towards the north. In area D, 19 pilot boreholes were drilled, of which 9 were converted into production wells. Maximum depth of aquifer zones is expected to vary from 200 to 400 feet below land surface. Discharge from wells has been computed at 295 to 1,195 USgpm for a drawdown of 20 feet. Static water-levels vary from 15 to 70 feet below ground-level subject to seasonal fluctuations of a few feet.

Area E — Shahpura-Bheraghat area: Area E north of the Narmada river is a roughly rectangular area about 13 miles long and 3½ miles wide extending Shahpura in the west to midway between Bheraghat railway station and Jabalpur in the east. Its southern boundary extends to within 1 mile of the River.

In this area 3 pilot boreholes were drilled of which only one was converted into a production well. The top of aquifer zones are expected to be encountered within 200 to 300 feet below land surface. Discharge from the lone production well completed in this area is estimated at 1,100 USgpm for an arbitrary drawdown of 20 feet. Static water-level varies between 15 and 35 feet below land surface, although this range, as in areas to the west, is subject to seasonal fluctuations of a few feet.

X. Areas not Suitable for Groundwater Development

For convenience in discussing that part of Narmada Valley that was explored for groundwater possibilities, but which proved barren, it has been broken down into five sections. Of these, one is the area west of Pagdhal (in promising area A) the other is between promising area A and Pawarkhera (in promising area B), another is just south of promising area D, and the fourth is between Kaurai (in promising area D) and Narsinghpur. The last one is north of the Narmada river, specifically at Udaipura.

The first area, represented by one borehole at Timurni, has been ruled out because of the inadequate thickness of the granular alluvial materials encountered here. In the Timurni borehole, Deccan trap was encountered at 103 feet below land surface and in the overlying alluvium, only one water yielding zone, at 56-66 feet, was found, but its yield was negligible.

Except at Samalkhera, the alluvium between Pagdhal and Pawarkhera is considerably thicker, as great as 390 feet at Dharamkundi. Even with this considerably thick alluvium, it was found to be virtually all clay or sandy clay; and attempts to produce water from the test-wells in this area were unsuccessful. At Samalkhera bed-rock was encountered at 78 feet and an attempt to pump water from the lateritic material encountered between 45-78 feet in this hole resulted in a yield of only 12 gallons per minute. Locally it may be possible to sink a well here which would have a fair to poor yield; but based on the apparent hydrological relationships in this area, the supply is on likely to be limited.

The land south of area D was ruled out on the basis of data obtained from two boreholes, — one at Semri and the other at Bankheri. The alluvium here is 550 to 700 feet thick; and the logs of both of them showed rather large sequences of sands and gravels. In the Semri well an aggregate of 100 feet of sand and gravel was encountered and in the other 123 feet of sand and gravel was penetrated. Preliminary, and, it is suspected, inadequate, pump testing at Bankheri showed the yield to be very low. The sand and gravel encountered in both wells were, however, found to be contaminated with clay with a resulting decrease in permeability. What would be the result of adequate construction and the development of tubewells drilled into the sand and gravel formations noted above, cannot, however, be assumed at this stage.

The well logs of 4 wells between the eastern edge of area D and Narsinghpur suggests that conditions here are comparable to those existing in the area described just above. Although a considerable thickness of alluvium exists here, 500 feet to above 700 feet, with aggregate thickness of sand and gravel that normally would yield copious quantities of water, the records uniformly show that enough brown or reddish brown clay is present to the permeability markedly.

At the Lakha borehole, the electric log showed the possible existence of aquifers below 380 feet. This evidence may not be enough to warrant drilling to considerable depth here; but not yield test was made at this hole.

At Udaipura, clay was encountered to a depth of 81 feet, overlying hard and compact Vindhyan sandstone. In this hole no satisfactory water-bearing material was encountered.

XI. Quality of Groundwater

Because the chief purpose of the exploratory programme is to determine the existence of groundwater for irrigation purposes an evaluation of the chemical character of water in the Narmada Valley should be made with that end in view. Yet it is not entirely feasible to attempt to appraise the utility of water for irrigation use solely from its chemical analysis. Many other factors, such as soil and crop types, climatic conditions and efficiency of subsurface drainage must be evaluated as well. However, a chemical analysis of the water will show whether or not the water will have any direct deleterious effect on crop growth and on soil character; and it is from this standpoint that the quality of water from the Narmada Valley is discussed here.

Based on the chemical analyses of a large number of samples of water collected from wells in the Narmada Valley, run in the Geological Survey of India laboratory, the following generalisations can be made :

i) *Total solids*: The content of total dissolved solids is sufficiently low (350-450 ppm), so that it is not expected to contribute to or to cause soil salinity.

ii) *Sodium content*: In none of the samples within the areas recommended for groundwater development is the sodium percentage above 50. There is, then, little danger of soil alkalisation with its adverse effect on the physical structure on the soil involved. As, for most of the waters analysed, the HCO_3 content is in excess of Ca plus Mg, precipitation of these alkali-earths may leave some residual HCO_3 in solution as sodium bicarbonate. For these particular waters, its concentration would be very small and the possibility of soil damage negligible.

iii) *Hardness*: From the standpoint of domestic use, the hardness content of these waters would be considered fairly high (250-300 ppm). However, for agricultural use this is not considered disadvantageous. As the hardness is «temporary», i.e., is caused by the occurrence of Ca and Mg as bicarbonates, these two constituents, Ca and Mg, will be precipitated as normal calcium and magnesium carbonate, an occurrence which certainly cannot be considered deleterious.

iv) *Boron*: For certain types of crops, notably citrus trees, the presence of even small quantities of boron in irrigation water is hazardous. Because a considerable part of the Narmada Valley is given over to the growth of oranges, a citrus crop, the need for the accurate determination of boron in water from deep wells is critical. This element was not determined in the Geological Survey of India laboratory. Although the boron content of the Narmada Valley waters is not known, it is believed that this element, if present at all, is below the concentration at which plant damage might occur. This conclusion is not final; and it is not intended to minimise the need for the quantitative estimation of boron in water (from tubewells) which is intended for use on citrus crops.

TABLE SHOWING THE YIELD AND DRAWDOWN FIGURES OF 16 PRODUCTION WELLS COMPLETED IN THE NARMADA VALLAY

Name and Number of borehole		Static water-level [(feet below measuring point (*a*)]	Date of measurement	Discharge * (U.S.g.p.m.)	Drawdown (feet)	Computed approximate yield in U.S.g.p.m. at 20 ft. drawdown (*b*)
Ari	33	37.33	December 16th, 1955	600	20.64	600
Shahpura	29A	16.01	January 18th, 1956	748	13.7	1095
Bakanj	36	27.94	February 10th, 1956	690	16.0	880
Kherua	37	21.27	» 27th, 1956	772	25.2	735
Babai	32	56.92	» 28th, 1956	656	24.0	570
Pipariya	23A	18.87	December 15th, 1955	350	47.0	180
Kheria	34	32.11	January 27th, 1956	450	26.2	345
Powerkhera	20	24.50	» 27th, 1955	310	5.6	1100
Pagdhal	17	47.0	April 13th, 1956	200	7.26	590
Gadarwara	26A	56.69	March 23rd, 1956	635	24.06	525
Sainkheda	25	52.08	» 17th, 1956	714	12.0	1195
Kauria	40	70.35	April 4th, 1956	455	19.57	470
Sobhapur	31B	38.70	May 7th, 1956	320	13.77	415
Pachlora	35	34.52	January 1st, 1956	739	19.0	815
Bareli	3	35.50	March 28th, 1956	396	21.63	366
Khapuria Kalan	2A	35.66	» 4th, 1956	685	21.92	585

* 1 U.S. gallon is equivalent to 0.833 Imp. gallon.
(*a*) Measuring point is the top of the casing at each well. It usually varies between 1.0 to 2.5 above land surface at site.
(*b*) Assuming specific capacity to be linear with yield.

CHEMICAL ANALYSES OF WATER FROM 16 PRODUCTION TUBEWELLS IN NARMADA VALLEY, MADHYA PRADESH AND BHOPAL

Analysts — B. K. Handa and S. H. Basu, Geological Survey of India

Borehole No. Locality Date of collection	*17 Pagdhal 13.4.56	20 Powerkheda 14.1.55	25A Sainkheda 17.3.56	*26A Gadarwara 23.3.56
Silica (SiO_2) P.P.M.	31	21	15	18
Iron & Aluminium Oxides ($Fe_2O_3 + Al_2O_3$) P.P.M.		7.0	1.4	
Iron (Fe) P.P.M.	0.06			2.6
Aluminium (Al) P.P.M.	0.12			
Calcium (Ca) P.P.M.	38.7	54	54	106
Magnesium (Mg) P.P.M.	16	16	15	38.5
Sodium & Potassium) P.P.M. (Na + K) as Na	168	72	12.6	43
Manganese (Mn) P.P.M.	trace			
Carbonate (CO_3) P.P.M.	14	Nil	Nil	9.7
Bicarbonate (HCO_3) P.P.M.	562	403	255	588
Sulphate (SO_4) P.P.M.	14.4	11	2.2	2.9
Chloride (Cl) P.P.M.	12	8	10.4	11.4
Nitrate (NO_3) P.P.M.	6.7		1.0	4.0
Nitrite (NO_2) P.P.M.				
Nitrate (NO_3) & Nitrite (NO_2) P.P.M.		10		
Dissolved solids at 180° C P.P.M.	603	408	233	518
Total hardness as $CaCO_3$ P.P.M.	164	202	197	423
Specific conductance (Micromhos at 25° C)	1005			
pH	8.3	7.9	7.5	8.3

* Computed results from the analyses of water sample and the precipitated matter in the bottle.

CHEMICAL ANALYSES OF WATER FROM 16 PRODUCTION TUBEWELLS IN NARMADA VALLEY, MADHYA PRADESH AND BHOPAL

(*Continued*)

Analysts — B. K. Handa and S. H. Basu, Geological Survey of India

Borehole No. Locality Date of collection	23A Piparia 15.12.55	29A Shapura 19.1.56	31B Shovapur 7.5.56	32 Babai 1.3.56
Silica (SiO_2) P.P.M.	7.4	25	18	19
Iron & Aluminium Oxides ($Fe_2O_3 + Al_2O_3$) P.P.M.				
Iron (Fe) P.P.M.	0.08	0.2	0.07	0.12
Aluminium (Al) P.P.M.	3.9	trace	trace	trace
Calcium (Ca) P.P.M.	81.5	40.2	78	83.6
Magnesium (Mg) P.P.M.	18.7	28.2	24	25.54
Sodium & Potassium (Na + K) as Na P.P.M.	24.7	30	21	52
Manganese (Mn) P.P.M.				
Carbonate (CO_3) P.P.M.	Nil	Nil	Nil	Nil
Bicarbonate (HCO_3) P.P.M.	389	339	393	502
Sulphate (SO_4) P.P.M.	Nil	3.95	Nil	8.7
Chloride (Cl) P.P.M.	10.5	6.5	12	11
Nitrate (NO_3) P.P.M.	2.6	2.4	4.8	4.0
Nitrite (NO_2) P.P.M.	Nil			
Nitrate (NO_3) & Nitrite (NO_2) P.P.M.				
Dissolved solids at 180° C P.P.M.	336	298	349	443
Total hardness as $CaCO_3$ P.P.M.	281	217	290	315
Specific conductance (Micromhos at 25° C)			595	
pH	7.6	7.7	7.1	7.3

Chemical analyses of water from 16 production tubewells in Narmada Valley, Madhya Pradesh and Bhopal
(*Continued*)

Analysts — B. K. Handa and S. H. Basu Geological Survey of India

Borehole No. Locality Date of collection	33 Ari 16.12.55	34 Kheria 24.1.56	35 Pachlaora 18.1.56	36 Bakanj 26.2.56
Silica (SiO_2) P.P.M.	18	4	4.8	8.3
Iron & Aluminium Oxides ($Fe_2O_3 + Al_2O_3$) P.P.M.	6			
Iron (Fe) P.P.M.		0.08	0.2	0.04
Aluminium (Al) P.P.M.		6	1	trace
Calcium (Ca) P.P.M.	60.5	91	82.5	74
Magnesium (Mg) P.P.M.	19.5	25	21.5	15.1
Sodium & Potassium (Na + K) as Na) P.P.M.	29	35	27	11
Manganese (Mn) P.P.M.		Nil	Nil	
Carbonate (CO_3) P.P.M.	Nil	Nil	Nil	Nil
Bicarbonate (HCO_3) P.P.M.	330	450	411	293
Sulphate (SO_4) P.P.M.	Nil	6.2	Nil	2.3
Chloride (Cl) P.P.M.	9.5	12.5	9	14.5
Nitrate (NO_3) P.P.M.	9.6	9.5	4	5.2
Nitrite (NO_2) P.P.M.	Nil	Nil	Nil	
Nitrate (NO_3) & Nitrite (NO_2) P.P.M.				
Dissolved solids at 180° C P.P.M.	310	401	356	284
Total hardness as $CaCO_3$ P.P.M.	232	331	296	248
Specific conductance (Micromhos at 25° C)				
pH	7.9	7.2	7.1	7.5

CHEMICAL ANALYSES OF WATER FROM 16 PRODUCTION TUBEWELLS IN NARMADA VALLEY, MADHYA PRADESH AND BHOPAL

(*Continued*)

Analysts — B. K. Handa and S. H. Basu, Geological Survey of India

Borehole No. Locality Date of collection	37 Kherua 12.2.56	40 Kauria 4.4.56	2A Khapuria Kalan 4.3.56	3 Bareli 28.3.56
Silica (SiO_2) P.P.M.	16	43	21	25
Iron & Aluminium Oxides ($Fe_2O_3 + Al_2O_3$) P.P.M.			12.5	1.5
Iron (Fe) P.P.M.	0.04	0.14		
Aluminium (Al) P.P.M.	trace	0.64		
Calcium (Ca) P.P.M.	80.6	55	56	54
Magnesium (Mg) P.P.M.	21.7	16	32	27
Sodium & Potassium (Na + K) as Na) P.P.M.	19.5	81	50	60
Manganese (Mn) P.P.M.		trace		
Carbonate (CO_3) P.P.M.	Nil	Nil	Nil	Nil
Bicarbonate (HCO_3) P.P.M.	363	418	435	435
Sulphate (SO_4) P.P.M.	2.4	13	2.55	2.14
Chloride (Cl) P.P.M.	10	14	8.4	7.9
Nitrate (NO_3) P.P.M.	6	1.05	2.6	2.2
Nitrite (NO_2) P.P.M.				
Nitrate (NO_3) & Nitrate (NO_2) P.P.M.				
Dissolved solids at 180° C P.P.M.	343	431	406	410
Total hardness as $CaCO_3$ P.P.M.		211	270	245
Specific conductance (Micromhos at 25°C)		631		
pH	7.2	7.3	7.4	7.7

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